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Kinematic Symmetry Index: a method for quantifying the horse locomotion symmetry using kinematic data

P Pourcelot¹*, F Audigié¹, C Degueurce¹,
JM Denoix¹, D Geiger²

¹ Biomécanique du cheval, Inra, École nationale vétérinaire d’Alfort, 7, avenue du Général de Gaulle, 94704 Maison-Alfort cedex;
² Laboratoire de mécanique physique, Université Paris-XII, avenue du Général de Gaulle, 94000 Créteil, France

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Summary – This study was conducted to evaluate a method for quantifying locomotion symmetry at trot in sound and lame horses. Using a 3D kinematic analysis system, the kinematics of the limb joints of sound and lame horses were recorded. The differences in motion between the left and right homologous joints were then quantified using a symmetry index based on an inter-correlation method. This method was used to calculate the symmetry indices of the vertical displacements and angle-time diagrams of the joints of each horse. In order to evaluate the sensitivity of this method of quantifying the locomotion symmetry, the symmetry indices of horses suffering from the three main types of lameness (forelimb, hind limb and bilateral lamenesses) were compared with those calculated for a reference group of clinically sound horses. The symmetry indices calculated using this method were sensitive enough to distinguish different degrees of lameness. Except for symmetrical bilateral lameness, the indices obtained also allowed us to determine which of the fore or hind limbs were lame. The results of this study make it possible to consider potential applications of this method in research and clinical fields.

Résumé – Index de Symétrie Cinématique : une méthode de mesure de la symétrie de la locomotion du cheval à partir de données cinématiques. L’objectif de cette étude est d’évaluer une méthode de mesure de la symétrie du trot de chevaux sains et boiteux. À l’aide d’un système d’analyse cinématique 3D, les trajectoires des articulations des membres de chevaux sains et boiteux ont été enregistrées. Les différences de mouvement entre les articulations homologues droite et gauche ont ensuite été quantifiées à l’aide d’un index de symétrie basé sur une méthode d’inter-corrélation. Cette méthode a été utilisée pour calculer les indices de symétrie des décours verticaux et angu-

* Correspondence and reprints
Tel: (33) 01 43 96 70 49; fax: (33) 01 43 96 31 62; e-mail: pourcelo@vet-alfort.fr
lares des articulations de chaque cheval. Afin d’évaluer la sensibilité de cette méthode de mesure de la symétrie locomotrice, les indices de symétrie de chevaux souffrant des trois principaux types de boiteries (antérieure, postérieure et bilatérale) ont été comparés à ceux d’une population de chevaux sains. Les indices de symétrie calculés à l’aide de cette méthode furent suffisamment sensibles pour distinguer différents degrés de boiterie. Sauf dans le cas de boiterie bilatérale symétrique, les indices obtenus permirent aussi de déterminer lesquels des membres antérieurs ou postérieurs étaient boiteux. Les résultats de cette étude permettent d’envisager l’application de cette méthode en recherche scientifique et clinique.

trot / cinématique / symétrie / boiterie / cheval

INTRODUCTION

Evaluation of locomotion symmetry is a central part of the diagnosis of equine lameness. This clinical examination is however essentially subjective. Different techniques have been used to quantify the locomotion symmetry of sound and lame horses. Merkens et al (1986, 1988, 1993) quantified the ground reaction force symmetry of sound and lame horses at the walk and normal trot. Barrey et al (1995) evaluated the gait symmetry and regularity of trotting horses using a belt with a mounted accelerometer. Kinematic techniques have also been used. Fredricson and Drevemo (1972) showed that the correlation between the kinematics of the extremity joints was strong between horses. May and Wyn-Jones (1987) and Buchner et al (1993) described quantification procedures in the movements of the hip. Kobluk et al (1989) and Martinez-del Campo et al (1991) compared the left and right angle–time diagrams. Recently, Buchner et al (1995, 1996a, b) evaluated the kinematics of the limbs and calculated the symmetry indices of the trunk during an induced lameness. However, no systematic study of the locomotion symmetry using kinematic data has been reported.

The aim of this study was to describe and evaluate a method for quantifying locomotion symmetry in sound and lame horses using kinematic data. A left-to-right symmetry index was defined and computed. This method was applied to the vertical displacement–time and angle–time diagrams of the left and right limb joints. Its sensitivity was evaluated by comparing the symmetry indices of horses suffering from the three main types of lameness with those of a reference group of sound horses.

MATERIALS AND METHODS

Horses

The reference group consisted of 13 sound French Warmbloods from the Régiment de Cavalerie de la Garde Républicaine. A detailed clinical examination confirmed that each horse was clinically free of lameness.

The group of lame horses consisted of three lame French Warmbloods suffering from the three main types of lameness. Their degree of lameness was scored by an experienced clinician according to the criteria used by Back et al (1993).

On the basis of clinical examination:

lame horse 1 presented a unilateral forelimb lameness due to navicular disease. It was moderately lame at trot (scored 2.0);

lame horse 2 presented a bilateral forelimb lameness due to pain on the sole. It was severely lame at trot (scored 3.0);

lame horse 3 presented a unilateral hind limb lameness due to an injury to the third interosseous muscle. At spontaneous trot it was slightly lame (scored 1.0) while after a dynamic flexion test it was severely lame (scored 3.0) during the first run and moderately lame (scored 2.0) during the second run.
Recording procedure and 3D reconstruction

Twenty-six markers were glued to the skin of the animal, six on each forelimb (shoulder, elbow, carpus, fetlock, coronet and hoof) and seven on each hind limb (tuber coxae, great trochanter, stifle, tarsus, fetlock, coronet and hoof). Great care was taken with regards to the symmetry of positioning the left and right markers. Four video cameras (50 Hz) were placed around a rubber examination track (Degueurce et al, 1996). These were focused to image a field of view 5.50 m long (fig 1). The horses were led by a well-trained operator at a slow trot (3.2 m/s) and filmed until at least five correct runs were made (Drevemo et al, 1980). The films were digitized by a video card with a resolution of 768 by 576 pixels and the successive positions of the markers determined. The 3D reconstruction of the trajectories of the markers was calculated using the direct linear transformation method (Abdel-Aziz and Karara, 1971).

Synchronization of the left and right movements

A computer program was developed to analyse the 3D kinematic data. In order for the left and right trajectories of a pair of markers to be compared and to calculate the symmetry indices, the movements of both left limbs of the horse with those of its right limbs were synchronized. This synchronization was obtained by inter-correlating the left and right longitudinal (X-axis) displacements of the four hooves. The program considered the displacements of both left hooves as the reference and shifted up the right ones frame by frame. Each time it calculated the coefficient of correlation between the left and the right displacements (fig 2). This operation was repeated until the maximum value of the coefficient was reached. The calculation of the coefficient was performed using half the total number of frames: if there were 100 frames in the file, the program would use, as references, the successive positions of both left hooves from frame number 25.

Fig 1. General view of the recording area.
to frame number 75. The first coefficient of correlation would be established using this reference and the successive positions of both right hooves from frame number 25 to 75 (fig 2, No 2). The result would be stored and the program would repeat the same operations with, now, the successive positions of both right hooves from frames 26 to 76, then from frames 27 to 77, and so on. Once the maximum value of the coefficient was reached (fig 2, No 3), the same calculations were performed but, now, shifting down the right longitudinal displacements until the other maximum value of the coefficient was reached (fig 2, No 1). In our example, the first coefficient would be calculated with the longitudinal displacements of both right hooves from frames 24 to 74, then from frames 23 to 73, and so on.

The highest value of these two maxima gave the number of frames by which both right limbs might be shifted to obtain the best synchronization of the longitudinal displacements of both pairs of hooves. This temporal synchronization was applied to all the markers of both right limbs. The other maximum gave another opportunity for synchronization. It appeared after, or before, another stride. The time interval between these two maxima corresponded to the stride duration.

**Calculation of the Kinematic Symmetry Indices**

In the following text, the term ‘symmetry indice’ refers to a pair of markers and the term ‘sym-
metrical index' refers to either the pair of fore or hind limbs.

The coefficient of determination at frame number \( i \) \( (r_i^2) \) between the left and right values of a kinematic variable calculated over one stride duration is:

\[
r_i^2 = \frac{\sum_{j=i}^{i+N_bF} [(R_j - \text{MeanR}) \times (L_j - \text{MeanL})]^2}{\sum_{j=i}^{i+N_bF} (R_j - \text{MeanR})^2 \times \sum_{j=i}^{i+N_bF} (L_j - \text{MeanL})^2}
\]

where \( N_bF \) is the total number of frames in the file; \( N_bFS \) is the number of frames for a single stride; \( L_j \) and \( R_j \) are the left and right values of the kinematic variable at frame number \( j \).

\( \text{MeanL} \) and \( \text{MeanR} \) are, respectively, the means of the \( L_j \) and the \( R_j \) between frame number \( i \) and frame number \( (i + N_bFS) \).

The symmetry indice of the kinematic variable (KSI) was the mean of the \( r_i^2 \) coefficients (fig 3)

\[
KSI = \frac{\sum_{i=1}^{i=N_bF-N_bFS} r_i^2}{N_bF - N_bFS}
\]

A value of 1.0 indicates perfect symmetry for the measured variable.

**Calculation of the Kinematic Symmetry Indexes**

The Kinematic Symmetry Index of the forelimbs (KSF) and the Kinematic Symmetry Index of the hind limbs (KSH) of the kinematic variable were computed by averaging the KSI of the fore and hind limbs, respectively.

**Kinematic variables studied**

The two kinematic variables studied in this paper were the vertical displacement-time and joint angle-time.

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![Fig 3. Sample calculation of the Kinematic Symmetry Indice (KSI). The KSI of a kinematic variable is the mean of the coefficients of determination \( (r_i^2) \) between its left (grey) and right (black) values calculated over one stride duration.](image-url)
For each joint, two KSI, one for the vertical displacement ($\text{KSI}_v$) and one for the joint angle ($\text{KSI}_\alpha$) were calculated by averaging the five trial values.

For each horse, four kinematic symmetry indexes were calculated, two for the forelimbs ($\text{KSF}_Z$ and $\text{KSF}_\alpha$) and two for the hind limbs ($\text{KSH}_Z$ and $\text{KSH}_\alpha$). They were computed by averaging the KSI of the fore and hind limbs, respectively.

**RESULTS**

Figures 4 to 9 present the values of the KS indices and indexes of the sound and lame horses. Assuming the indices of the sound horses were normally distributed, the values lower than two standard deviations below the mean of the sound ones ($P < 0.05$) were outside the 95% confidence interval. Consequently they were not considered as sound values. For these abnormal values, a dark square is visible in the figures.

The means of the vertical displacement $\text{KSI}_v$ of the sound horses (fig 4) ranged from 0.88 to 0.95 for the forelimbs with a $\text{KSF}_Z$ index of 0.92 and from 0.82 to 0.95 for the hind limbs with a $\text{KSH}_Z$ index of 0.88. All the joint angle-time diagrams $\text{KSI}_\alpha$ were greater than 0.96 except for the fore and hind coffins.

Lame horse 1 suffered from a unilateral forelimb lameness (fig 5). The $\text{KSI}_Z$ of the three proximal markers of the forelimbs were lower than two standard deviations below the mean of the sound horses. Its $\text{KSF}_Z$ and $\text{KSH}_Z$ indexes were 0.75 and 0.89, respectively.

A bilateral forelimb lameness was present in lame horse 2 (fig 6). Its $\text{KSF}$ index was not affected significantly, nevertheless the $\text{KSI}_Z$ of the shoulder was lower than two standard deviations below the mean $\text{KSI}_Z$ of the sound horses. The KSH indexes and all the hind limb KSI were greater than those of the sound horses.

Lame horse 3 presented a unilateral hind limb lameness (fig 7). Its $\text{KSF}$ indexes were similar to those of the sound horses but its $\text{KSH}_Z$ index was 0.71 as opposed to a standard sound value of 0.88. All the $\text{KSI}_Z$ of the forelimbs were greater than two standard deviations below the mean of those of the sound horses, whereas, for the hind limbs, only the stifle and the fetlock presented this same characteristic. During the first run after the flexion test of lame horse 3 (fig 8), all the $\text{KSI}_Z$ of the hind limbs were significantly lower than those of sound horses. The $\text{KSH}_Z$ index decreased from 0.71 at spontaneous trot to 0.34. The $\text{KSF}_Z$ index decreased from 0.92 to 0.85. This decrease was due to the $\text{KSI}_Z$ of the shoulder and elbow, which were lower than 0.69. During the second run (fig 9), the $\text{KSH}_Z$ index rose to 0.60 and the forelimb asymmetry disappeared ($\text{KSF}_Z$ index went back to 0.93).

**DISCUSSION**

This study describes a method for quantifying the locomotion symmetry by calculating symmetry indices between the left and right values of a kinematic variable. The critical part of this calculation is the synchronization of the movements of both left limbs of the horse with its right ones.

The reference variables used to obtain the most suitable synchronization must satisfy three conditions. They should be:
- based on the most symmetrical kinematic variable of sound and lame horses;
- representative of the whole locomotion;
- the most discriminating as possible.

When trotting at constant speed and in a straight line, the stride lengths of both right limbs of a sound or lame horse are necessarily very close to those of the two left limbs (Peloso et al, 1993). Thus, the longitudinal displacements values of the lame horse markers remain symmetrical, as
Fig 4. Mean symmetry indices of a group of 13 sound horses. KSF is the Kinematic Symmetry Index of the forelimbs; KSH is the Kinematic Symmetry Index of the hind limbs.
Fig 5. Symmetry indices of lame horse 1.
Fig 6. Symmetry indices of lame horse 2.
Fig 7. Symmetry indices of lame horse 3 at spontaneous trot.
LAME HORSE 3
UNILATERAL HIND LIMB LAMENESS
FIRST RUN AFTER THE FLEXION TEST
SCORED 3.0

Vertical displacement symmetry indices

Joint angle symmetry indices

Fig 8. Symmetry indices of lame horse 3 during first run of a flexion test.
LAME HORSE 3
UNILATERAL HIND LIMB LAMENESS
SECOND RUN AFTER THE FLEXION TEST
SCORED 2.0

Vertical displacement symmetry indices

Joint angle symmetry indices

Fig 9. Symmetry indices of lame horse 3 during second run of a flexion test.
opposed to the transversal and vertical ones. To fulfill the second condition, it is necessary to choose a set of longitudinal displacement values on both left and right limbs of the animal as reference. Furthermore, the more distal the selected markers are located, the greater the acceleration readings are, and therefore the more discriminating the synchronization becomes. Consequently, the most suitable reference variables to synchronize the movements of both lateral bipeds are the longitudinal displacements of both hooves paired left and right.

As opposed to symmetry indices based on the ratio of extreme or mean values, this method takes into account the whole shape of the curves. Nevertheless, it presents two main limitations. First, it cannot determine the lame limb side. For example, lame horse 1 presented an unilateral forelimb lameness (scored 2.0). Its KSH indexes were similar to those of sound horses but its KSFZ index was 0.75 as opposed to a standard sound value of 0.92. It was apparent that the lameness proceeded from the forelimbs, but more investigations were necessary to determine which forelimb was involved. Second, this method was unable to detect symmetrical bilateral lamenesses. Lame horse 2 suffered from a bilateral forelimb lameness (scored 3.0); nevertheless, because of the lack of locomotor asymmetries (Buchner et al, 1995), none of its KSF or KSH indexes was affected significantly. Once again, further analysis was required.

The resolution of the system and/or an asymmetrical placement between the left and right markers could affect the values of the KSI. However, these methodological errors do not alter the general shape of the curves (Kadaba et al, 1989). Thus, they do not affect significantly the values of the symmetry indices, because their calculation is based on a correlation method. The error of the vertical displacements and joint angle-time diagrams has been evaluated relative to an asymmetrical placement of the markers (Audigé et al, 1996). It represents less than 2% of the values of the KS indexes, except for the coffin joint angle where it reaches 4%.

The real advantage of this method is that the calculated indices are sensitive enough to distinguish between different degrees of lameness. Lame horse 3 presented an injury to the third interosseous muscle of the right hind limb. At the trot, it shows a low degree of lameness (scored 1.0). Its KSHZ index was 0.71 as opposed to a standard sound value of 0.88. The values of these indices were strongly affected by a dynamic flexion test. During the first run (scored 3.0), the KSHZ index fell down to 0.34 inducing a light forelimb asymmetry with a KSFZ index of 0.85. This forelimb lameness is observed on the proximal markers. During the second run (scored 2.0), the hind limb lameness is attenuated, the KSHZ index increases to 0.60 and the forelimb asymmetry disappears.

The vertical displacement indices are generally lower but more sensitive than the joint angle ones. During the second run after the flexion test, all the hind limb KSI of lame horse 3 are significantly lower than the standard sound ones although only the KSI of the coffin joint is significantly affected. This lower sensitivity may be due to two different causes. On the one hand, the shape of the angle–time diagrams curves are smoother than the vertical displacement–time ones. On the other hand, the lameness impact is lower on the shapes of the joint angle–time diagrams curves than on the vertical displacement–time ones. The KSI values of the tuber coxae, great trochanter and stifle are 0.12, 0.19 and 0.02, respectively, during the first run when the hip KSI stands at 0.98. It shows that the vertical displacements of the proximal left and right markers are strongly asymmetrical while the general shape of their associated joint angle–time diagrams curves are unaffected.
This analysis method of the locomotion symmetry can be used with other gait analysis variables. It is applicable within the frame of a standard clinical lameness examination. For each joint, it provides the clinician with an objective quantification of the symmetry level. Nevertheless further analyses with a higher number of lame horses are required. This would make it possible to evaluate the ability of this method to detect and quantify the degree of subtle lameness, which may have potential applications in research and clinical studies.

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